Sophisticated humanoid robot control

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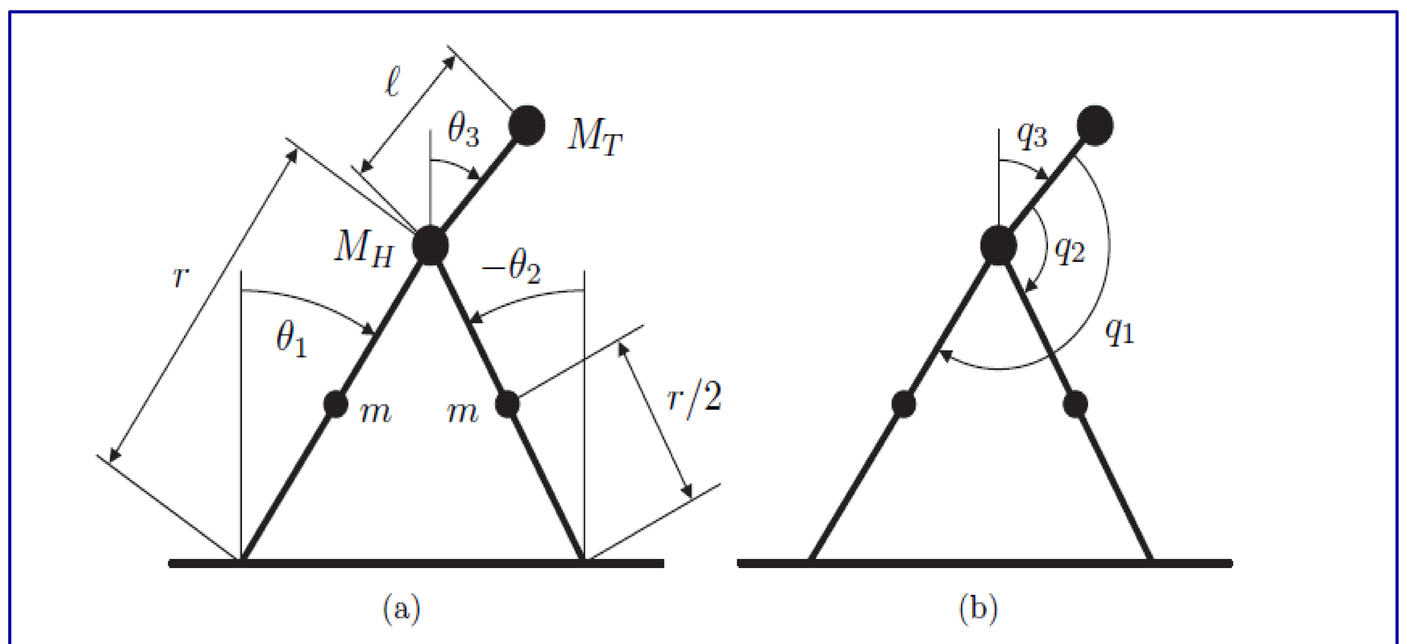
ABSTRACT

In the legged robotics control literature feedback linearization is mostly used till date, along with computed torque control, variable structure control, optimal and adaptive control. The biped robot control locomotion in general addresses the following three problems. Firstly, the reference trajectory is planned based on the stability analysis of the robot (ZMP/FRI). Then it is also desirable to obtain a minimum jerk humanistic movement. Moreover the robot actuators have obvious physical limitations. It is interesting to note that the above pattern of problem formulation naturally fits into the MPC framework. This work explores the existing void in this direction. One of the advantages of MPC is also that robust control ideas can be easily incorporated. A non-linear MIMO dynamical system of a three link biped robot with rigid, point feet would be considered for simulation purposes.



The model is indicated in: a) Generalized coordinates b) Body (also called shape) coordinates

1. The hybrid model of walking

Swing phase model

Corresponds to a pinned kinematic chain. The model is easily obtained with the method of Lagrange, which consists of first computing the kinetic energy and the potential energy of each link, and then summing terms to compute the total kinetic and total potential energy

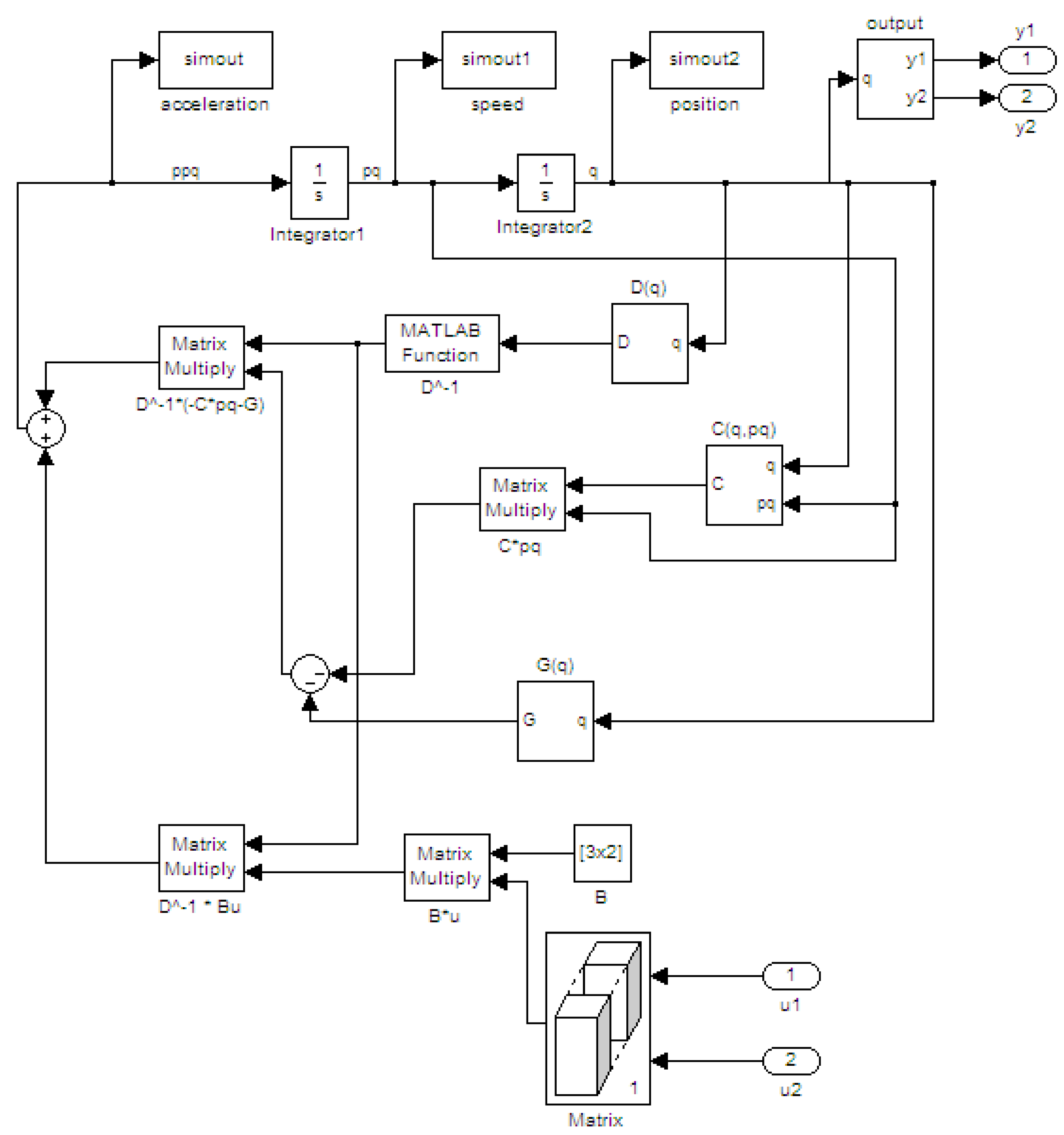
$$D_s(q_s)\ddot{q}_s + C_s(q_s,\dot{q}_s)\dot{q}_s + G_s(q_s) = B_s(q_s)u$$

Impact model

The development of this model involves the reaction forces at the leg ends. Using the generalised coordinates the method of Lagrange results in the following model.

$$D_e(q_e)\ddot{q}_e + C_e(q_e,\dot{q}_e)\dot{q}_e + G_e(q_e) = \mathrm{B}_e(q_e)u + \delta F_{ext}$$

$$\Sigma: \begin{cases} \dot{x} = f_s(x) + g_s(x)u & x^- \notin Surface\ (swing) \\ x^+ = \Delta(x^-) & x^- \in Surface\ (impact) \end{cases}$$



The above Simulink diagram represents the swing phase model of the biped locomotion.

2. Computed torque control

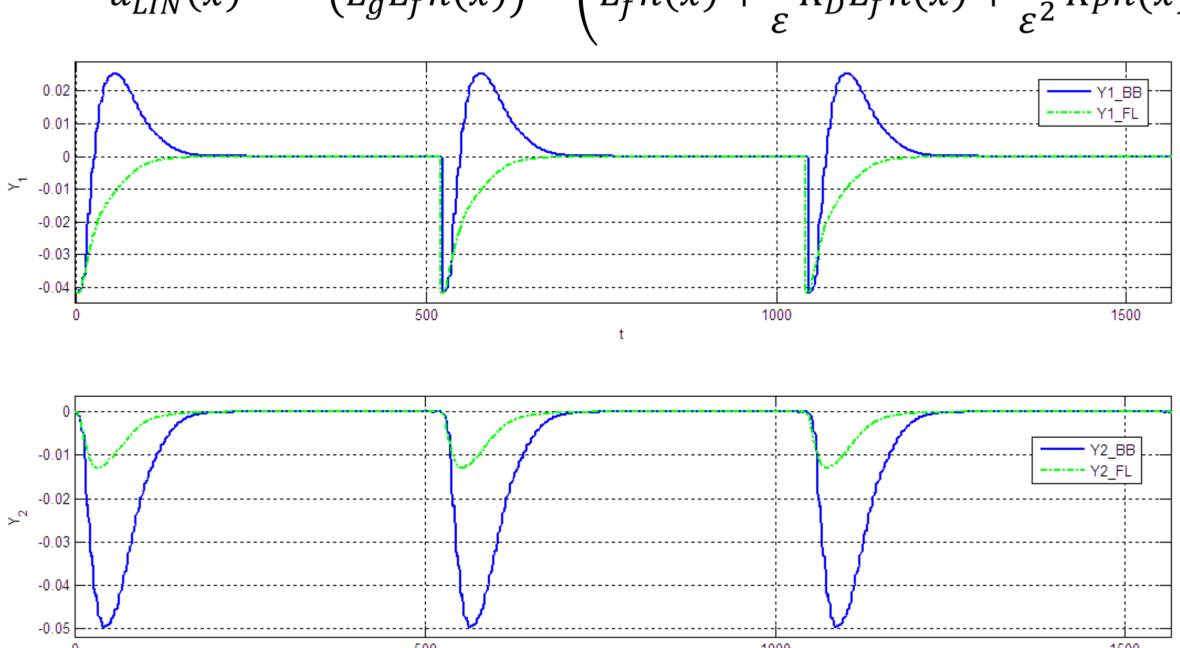
Decoupling of the system is done through Lie derivatives ($L_g L_f h(x)$ is called decoupling matrix).

Linear feedback controller tuning:

$$u_{LIN}(x) = -\left(L_g L_f h(x)\right)^{-1}\left(L_f^2 h(x) + \frac{1}{\varepsilon}K_D L_f h(x) + \frac{1}{\varepsilon^2}K_P h(x)\right)$$

Proportional and derivative gains were tuned in order to achieve better performance (settling time and overshoot).

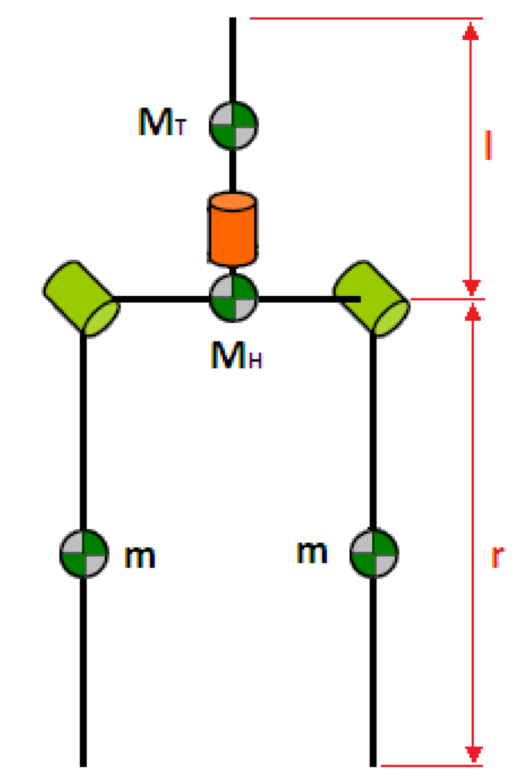
$K_D = 10$
$K_P = 15$



Why point feet?

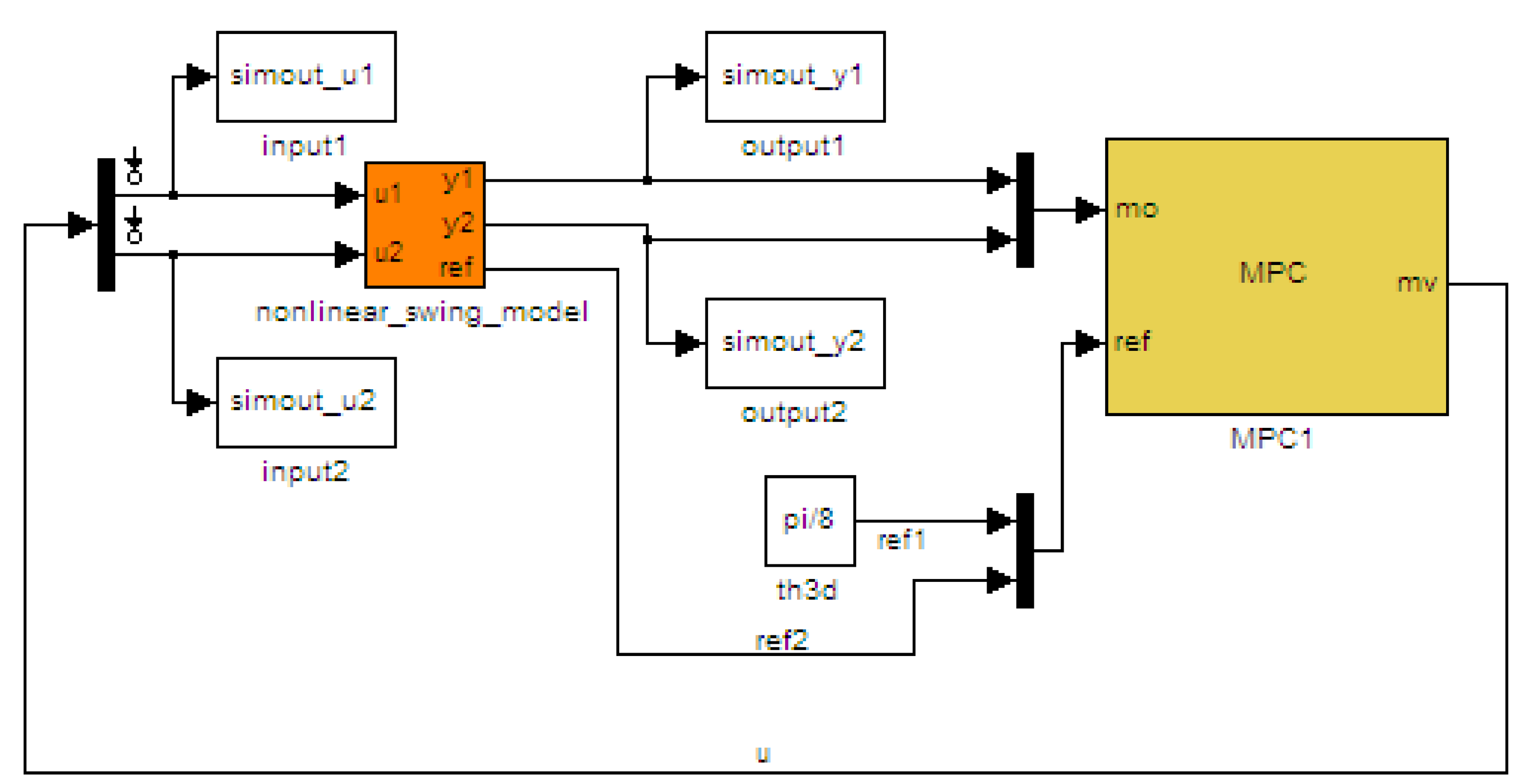
- Simpler
- Is an integral part of an overall model of walking with toe, which is anthropomorphic, and much more complex

Parameter	Notation	Units	Value
Torso length	l	m	0.5
Leg length	r	m	1.0
Torso mass	M_T	kg	10
Hip mass	M_H	kg	15
Leg mass	m	kg	5
Acceleration due to the gravity	g	m/s^2	9.81



3. MIMO MPC

The first approach to the problem is linearization of the MIMO system, which has six states. MPC is proposed for optimal tracking (with prediction horizon = 30 and control horizon = 4).



A Simulink control scheme is included above.

4.Asymptotically stable walking

Basically walking consists of:

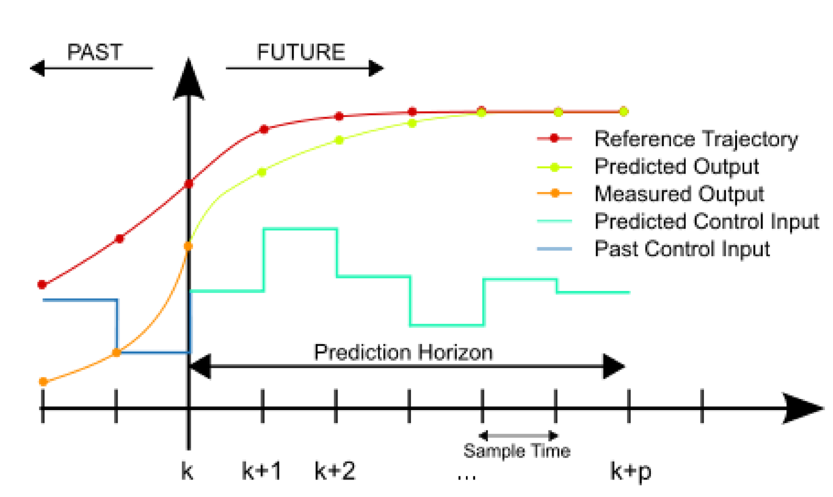
- posture control, that is, maintaining the torso in a semi-erect position;
- swing leg advancement, the leg behaves as the mirror image of the stance leg.

The goal of the control design is to induce an asymptotically stable walking cycle, and to facilitate the verification of its existence and stability properties. The verification will be done using the method of Poincaré.

5. NEPSAC

➢Further development include:

Apply Nonlinear Extended Prediction Self-Adaptive Control (NEPSAC) without linearizing the model, by other words, the nonlinear model is directly used to calculate the base responses, and the step-response coefficients (which form the G matrixes). In the iterative procedure it is expected that U_{base} will converge to the optimal U.



MPC Principle

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